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A FIRST COMET MISSION

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AND STRATEGIES FOR A FIRST COMET MISSION.
REPORT OF THE COMET HALLEY SCIENCE WORKING
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EXECUTIVE SUMMARY

Report of the
Comet Halley Science Working Group

July 1977



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SCIENTIFIC RATIONALE AND STRATEGIES
FOR A FIRST COMET MISSION

AN EXECUTIVE SUMMARY

REPORT OF THE COMET HALLEY SCIENCE WORKING GROUP

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July 1977

The Comet Halley Science Working Group (CHSWG) met four times in 1977 to consider the scientific objectives, strategy, and instrumentation for a first comet mission. Their findings have been published in a separate report which is summarized here.

JUSTIFICATION

A successful mission to a comet could lead to major advances in our understanding of basic physical and chemical processes in cosmogony, molecular astronomy, and space physics.

- (1) Comets are a substantial component of the solar system with a total mass of planetary magnitude. For unknown reasons, this mass condensed into small bodies for which the internal pressure and temperature were not sufficient to cause differentiation or other physical changes. Thus comets are probably the most pristine, primitive objects available for studies of the evolution of the solar system. Furthermore, the outer skin of a comet is removed during each close passage by the Sun to expose fresh material for analysis. Measurement of the composition and physical constitution of comets will thus yield fundamental information on the chemical and physical conditions that existed near the time of planetary formation and on the processes of condensation, agglomeration, and mixing which were taking place.
- (2) Comets may contain pre-solar system or interstellar grains, both of which are otherwise unavailable for study.
- (3) Comets may have been a major source of organic materials in the atmospheres of the terrestrial planets. Thus a study of their composition should provide clues about the nature of the pre-biological environment on Earth.
- (4) Most of the detailed knowledge concerning the state of the formative solar system has come from studies of meteorites. The principal uncertainty is the source(s) of meteorites. A comet mission could establish the relations between comets and meteorites of different classes, as well as between comets and interplanetary dust, meteoroids, and the Apollo asteroids.

- (5) Since the composition of comets appears to be similar to that of interstellar clouds, the study of comets may help solve major problems concerning molecule formation and the nature of interstellar clouds and dark nebulae. Some cometary molecules may be the molecular precursors of life.
- (6) Whipple's icy conglomerate theory is the most widely accepted theory of the nature of cometary nuclei. Close examination of a comet is needed to test this theory.
- (7) The physical mechanisms responsible for the rapid dissociation and ionization of cometary gases and their acceleration into the ion tail are not understood. In situ studies of such cometary phenomena appear essential for the clarification of these processes. Also, such observations can yield new insights into certain geomagnetic and astrophysical phenomena.
- (8) Comets are unique free probes of the interplanetary medium, but in situ observations are required to establish the link between cometary and solar wind conditions and ground-based observations.

SCIENTIFIC OBJECTIVES

In order to obtain data relevant to these scientific questions, a first comet mission should address the following objectives:

- (1) Determine the chemical nature and physical structure of the nucleus.
- (2) Characterize the physical evolution of the nucleus during its passage by the Sun.
- (3) Characterize the evolving chemical and physical nature of the atmosphere, ionosphere, and dust envelope.
- (4) Characterize the interaction of the comet with the interplanetary plasma and determine the origin and physical nature of comet tails.

NATURE OF THE FIRST MISSION

Types of missions, in order of increasing scientific return, are flyby, rendezvous, landing, and sample return. The great uncertainty about the nature of the surface of a comet makes a mission aimed at a sample return or a

landing extremely difficult and expensive. Fortunately, most of the scientific objectives can be accomplished with a rendezvous, in which the spacecraft's orbit matches that of the comet with zero relative velocity. The CHSWG strongly recommends that the first comet mission be a rendezvous rather than a flyby for the following reasons:

- (1) Cometary activity varies rapidly with time. The many levels and types of activity can not be studied with a flyby which lasts for minutes or hours, but only with a rendezvous which lasts for months.
- (2) The location of the spacecraft relative to the comet can be controlled to meet scientific needs.
- (3) Better data are obtained from most instruments. Many of the instruments recommended for a rendezvous mission are not sufficiently sensitive to be used on a flyby.
- (4) Because of the low relative velocity, there is less hazard due to impact by cometary solids.
- (5) It is possible to terminate a rendezvous mission with an experimental landing on the nucleus.

SELECTION OF MISSION TARGET

Comet Halley is by far the best target for a first comet mission.

- (1) It has a well determined orbit and has demonstrated fairly reliable behavior over a period of two millennia.
- (2) Because it is much brighter and has a greater gas production rate than any other short period comet, more accurate and sensitive measurements of its chemical composition are possible.
- (3) It is the only short period comet to display the full range of cometary phenomena.
- (4) It is probably one of the freshest of the short period comets.
- (5) It is perhaps the only short period comet well known to the public.

STRATEGY FOR A RENDEZVOUS MISSION

Many cometary phenomena can be observed only when the comet is within ~1.5 AU of the Sun. Thus the CHSWG strongly prefers that rendezvous with Halley occur before it reaches perihelion (heliocentric distance = 0.6 AU), or, if this is not feasible, as close to the Sun as possible after perihelion.

The possible dangers associated with a close approach to a comet dictate that the mission strategy must be highly adaptive with spacecraft response times of a day or less. The nucleus should be approached slowly, making sequential measurements of physical properties and processes of ever decreasing scale. At least a day should be spent within 10 km of the surface of the nucleus.

The dependence of tail phenomena on activity near the nucleus is best studied with a specially instrumented tail probe which is deployed from the main spacecraft near rendezvous and flies a ballistic trajectory millions of kilometers down the tail.

After the primary scientific objectives of the mission have been attained, the mission should end with an experimental attempt to land on the nucleus.

It is not possible to rendezvous with Halley, or with any other comet, by means of a ballistic launch from Earth. Two low-thrust, high-energy propulsion systems under development, the ion drive and the solar sail, can deliver a substantial payload to rendezvous with Halley's comet. The CHSWG notes the following differences between the two systems insofar as the impact on the scientific observations is concerned.

- (1) The ion drive can rendezvous with Halley before it passes through perihelion, whereas the solar sail cannot rendezvous until a heliocentric distance of at least 1 AU postperihelion.
- (2) The ion-drive approach trajectory is superior to that of the solar sail. It approaches from the sunward side and can observe the main upstream features expected in the comet-solar wind interaction. The phase angle of the ion drive approach allows better viewing of the nucleus.

- (3) When the ion thrusters are on, which is almost continuously during cruise and a fraction of the time after rendezvous, the ion-drive system is a much greater source of interference with fields and particles measurements than is the solar sail.
- (4) The solar-sail spacecraft is more likely to survive and be able to operate after a landing on the nucleus.

SCIENTIFIC INSTRUMENTS

A typical complement of scientific instruments for a rendezvous mission is listed in Table 1 together with the primary measurement objectives, the desired capabilities, and the development status of each instrument. The total mass of all these instruments is approximately 120 kg, which is compatible with both the ion drive and the solar sail capabilities.

Table 2 shows a possible complement of instruments for a tail probe. The total probe mass is 55 to 60 kg.

Tables 1 and 2 illustrate that it is possible to achieve major contributions to all of the scientific objectives with developed or conceptually feasible instrumentation. Where needed, instrument development is currently underway; specifically, better ion mass-velocity spectrometers and dust analyzers are under development in several laboratories. Although methods of protection against dust must be developed for many of the instruments, concepts exist and the dust-hazard problem appears to be surmountable.

BACKUP MISSIONS

If it becomes clear that it is not possible to achieve a rendezvous with Halley's comet, the CHSWG prefers a fall-back strategy of a rendezvous with another comet over a flyby of Halley's comet at any distance. The best alternate targets are Comets Encke and Giacobini-Zinner.

SUPPORTING RESEARCH

In order to increase the probability of success of a first comet mission and to enhance the scientific return, the CHSWG recommends that NASA provide strong support in the following areas:

- (1) Theoretical modeling of physical conditions and processes in cometary atmospheres.
- (2) Supporting laboratory experiments.
- (3) Further development of flight instruments for a comet mission.
- (4) Ground-based observations of Halley and other comets.
- (5) Pre- and post-mission simulation of flight experiments.

Table 1. Primary Measurement Objectives and Capabilities of Typical Instruments for Rendezvous

INSTRUMENT	PRIMARY MEASUREMENT OBJECTIVES	DESIRED INSTRUMENT CAPABILITIES	FLIGHT INSTRUMENT DEVELOPMENT STATUS
Neutral Mass Spectrometer	Identification of "parent" molecules Atmospheric chemistry and neutral gas flow Isotopic composition of volatiles	Mass range: 1-250 AMU Mass resolution: $\Delta m = 1$ AMU (1-250 AMU) poorer resolution acceptable at higher mass numbers Dynamic range: $\sim 10^8$ Sensitivity: $\geq 10^3$ Mol. cm^{-3}	Good instruments exist Add dust protection
Thermal Ion Spectrometer	Ionic composition, temperature and velocity Identification of ionization mechanisms near comet	Mass range: 1-100 AMU (at least) Mass resolution: $\Delta m = 1$ AMU Sensitivity: $n \geq 1$ ion cm^{-3} $T > 150^\circ\text{K}$ $V > 40$ m s^{-1}	Good instruments exist Add dust protection
Ion Mass and Velocity/ Solar-Wind Analyzer	Acceleration of ions near comet to form tail Interaction of solar wind with comet (bow shock; contact surface: stability)	Mass range: 1-100 AMU Mass resolution: $\Delta m = 1$ AMU Velocity range: 1-400 km s^{-1} Flux range: $10^4 - 10^9$ cm $^{-2}$ s $^{-1}$ ion $^{-1}$	Need better mass resolution than available Need dust protection
Magnetometer	Magnetic properties of ionosphere and relation to ionization and ion acceleration mechanisms Interaction of solar wind with comet Magnetic field of nucleus	Field range: $10^{-1} - 10^3$ γ 3 axis type; rapid response	Good instruments exist
Plasma Wave Detector	Relation of plasma and field instabilities to ionization and ion acceleration mechanisms Interaction of solar wind with cometary atmosphere	Wave modes: electrostatic, hydro-magnetic, electromagnetic Response: $\sim 10^{-1} - 10^5$ Hz Sensitivity: $> 10^{-1}$ γ $> 10^{-5}$ v m $^{-1}$	Good instruments exist
Electron Analyzer	Ionization phenomena near nucleus Interaction with comet of solar wind	Energy range: ~ 1 eV to several keV Sensitivity: 0.1 - 10^5 electrons cm $^{-3}$	Good instruments exist Need dust protection
Ultraviolet Spectrometer	Atmospheric and ionic composition and production rates Scales of observable species Dust albedo and distribution about comet	Wavelength range: 1100 - 4000 Å Resolution: ~ 10 Å	Good instruments exist Need dust protection
Near IR Spectrometer	Chemical homogeneity of nucleus Identify some ices and non-volatiles	Wavelength range: 0.8 - 5 μm Resolution: 50 - 100 Å Field of view: 10^{-3} rad	Current technology adequate Reconfigure to optimize for comet mission Need dust protection Special cooling requirement
Imaging	Gross physical properties of nucleus (size, shape, rotation, optical properties) Physical heterogeneity of nucleus Disintegration of surface of nucleus Navigation	Sensor: CCD (800 x 800) Wavelength range: 3000 - 10,000 Å Spatial resolution/FOV: 2 x 10^{-5} rad/0.47 deg 7 x 10^{-4} rad/16 deg	Telescopes exist CCD's under development (vidicon fallback) Need dust protection
Radar Altimeter	Mass of Nucleus Supplements Imaging Objectives Navigation Surface properties of nucleus (dielectric constant; roughness)	Range: ≤ 50 m or 10^3 km Velocity: ≤ 1 m s $^{-1}$	Current technology adequate

Table 1. Primary Measurement Objectives and Capabilities of Typical Instruments for Rendezvous (contd)

INSTRUMENT	PRIMARY MEASUREMENT OBJECTIVES	DESIRED INSTRUMENT CAPABILITIES	FLIGHT INSTRUMENT DEVELOPMENT STATUS
IR radiometer	Temperature and emissivity of surface of nucleus Thermal inertia of surface of nucleus	Wavelength range: 10 - 100 μm Resolution: $\sim 1 - 10 \mu\text{m}$ FOV: $\sim 10^{-3}$ rad	Good instruments exist Cooling problem Need dust protection
Orbital X-ray Fluorescence	Elemental abundance ratios for certain non volatiles (Al, Si, Mg, Ca, Ti, Fe) Relationship to meteorites	Energy range: 0.5 - 9 keV	Good instruments exist Cooling problem for detector
Dust Particle Counter and Analyzer	Dust flux and mass distribution Assessment of dust hazard Dust composition Charge	Velocity range: $> 10 \text{ m s}^{-1}$ Mass Threshold: 10^{-13} g $m/\Delta m: \sim 100$	Need to decrease velocity threshold by 1 or 2 orders of magnitude Need to increase mass resolution by order of magnitude (if used in composition mode)
Collected Dust Analyzer	Elemental abundance ratios for certain non volatiles Relation to meteorites	1) α -scattering/X-ray fluorescence; dust sample volume: $\sim 0.1 \text{ cm}^3$ 2) SEM-EDX type; only individual particles need to be collected	Dust collector needs study and development 1) Sensors and analyzers proven 2) Development needed
Landed Science	Temperature of surface (calibration of IR radiometer?) Surface strength Experience/exploration	1) Accelerometer 2) Thermal sensor 3) Imaging adapter 4) Anchor 5) Etc.	1) Good instruments exist 2) Good instruments exist 3) Need study and development 4) Need study and development

Table 2. Tail Probe — Typical Payload

INSTRUMENT	MASS, kg	POWER, w	DATA RATE, bps	HERITAGE	COMMENTS
Magnetometer	2.7	5.8	4	ISEE-B (Actual)	Magnetometer mounted on boom
Plasma Wave Detector	4.3	3.1	6	ISEE-B (Actual) (2.9 kg plus 1.4 kg for 30 m tip-to-tip antenna with motor)	Search Coil on boom. Short electric antenna on boom. "Long" antenna body-mounted. 2.9 kg includes elec- tronics, short electric antenna, search coil, and pre-amps.
Plasma Probe + Mass Analyzer	9.0	4.0	7	New: Based on various JOP proposals.	Must have capability to measure electrons, protons in solar wind, sheath region, and comet tail, plus capability for mass analysis in the tail region.
Dust Impact Counter and Analyzer	5.0	10.0	3	Helios (type)	May require time-sharing to meet a reduced power budget.
TOTAL	21.0	22.9	20		